RATIONAL USE OF WATER AND SOIL MANAGEMENT UNDER A CENTER PIVOT SYSTEM

JOÃO CARLOS CURY SAAD[1]; MARCELO AUGUSTO DE AGUIAR E SILVA[2]; LEONARDO PRETTO DE AZEVEDO[2]

[1]Professor, Agricultural Science School, São Paulo State University, Rua José Barbosa de Barros, 1780, Botucatu, SP, 18610-307, Brazil; joaosaad@fca.unesp.br
[2]Graduate, Agricultural Science School, São Paulo State University, Rua José Barbosa de Barros, 1780, Botucatu, SP, 18610-307, Brazil.

ABSTRACT

Currently the demand for water resources has increasing as a result of population pressure and industrial developments. In Brazil, about 70% of the available water resources are used for agriculture purposes. The adoption of rational techniques for soil and water conservationist management is vital for sustainability so that these resources will be preserved along time with sufficient quantity and quality for the maintenance of satisfactory productivity levels in agriculture. The conventional soil management has been successfully replaced in many agricultural regions worldwide and particularly in Brazil. In the last decades, the quick degradation of soil under agricultural exploitation worldwide, especially in tropical developing countries has arisen the concern on soil quality and sustainability of the agricultural exploitation. The no-tillage system presents as main characteristic the implementation of culture without drastic soil mobilization, in other words, without its preparation or mobilization before sowing, the mobilization occurs only at the sowing line. This type of system also involves the maintenance of vegetal residues from previous cultures at its surface and the diversification of species through culture rotation. The maintenance of residues at the soil surface in the no-tillage system, besides the increase on the water retention, also has a great potential to reduce irrigation water requirement. The objective of this work was to evaluate how two different soil management systems, conventional and no-tillage, influence the soil water retention, irrigation water requirement, compaction, root development and bean yield, irrigated by center pivot system. The study was conducted at the farm of an irrigating producer in the largest irrigated region of the state of São Paulo, Brazil, during the second semester of 2003. The culture selected was bean cultivar Rubi, which sowing occurred at August 02 and harvest at November 25, summing up 116 days of culture cycle. The experimental design was fully randomized with two treatments and 13 repetitions. The experimental parcels were placed under an 18 ha central pivot and divided into two soil management types: conventional and no-tillage. Although no-tillage management presented higher water retention and lower compaction at the most superficial soil layers as well as more uniform root distribution in the soil profile, the soil managements did not present significant differences in relation to crop productivity. It was verified that the no-tillage management generated indirect benefits like reduction in the irrigation water requirement. Since conservationist management cycles are short, time was not enough to promote structural changes in the soil and hence significant alterations in the physical-hydric properties that would lead to higher root development and crop yield.

Keywords: no-tillage management, productivity, available water, central pivot.

INTRODUCTION AND BACKGROUND

Soil Management

In natural conditions, soil is found in a stable state in relation to the environment; however, inadequate management leads to degradation especially of the organic fraction, thus compromising the sustainability of agricultural systems (Gonçalves & Ceretta, 1999). The structure of an ideal soil allows adequate contact area between roots and soil, a continuous, porous and sufficient space for the movement of water and gases and soil resistance to penetration that would not limit the root growth (Koppi & Douglas, 1991). Due to soil management, the soil is passible both of degradation and of improvement of the productive potential. The different management systems cause alterations on the soil density and porosity and hence on the water storage along its profile, directly influencing the development of the root system and culture productivity. The magnitude of these alterations is a function of the management system adoption time, type of soil and climate of the region. The management systems must adapt to edaphoclimatic, social and regional cultural conditions and contribute for the maintenance or improvement of the soil and environment quality as well as for the attainment of adequate productivity along the years (Costa et al., 2003).

Conventional Soil Management

The conventional soil management is a set of operations performed before sowing with the objective of revolving the soil in order to provide the best physical, chemical and biological conditions for the seed to germinate, besides incorporating fertilizers, correctives and remainders of previous cultures; this latter, as a way to control weeds (Folle & Seixas, 1986). However, the use of this practice for successive years, besides causing excessive physical disintegration and superficial soil management (0.12 to 0.15m), it may also lead to the formation of an impermeable layer underneath the soil surface, known as “grid foot or plow foot” (Freitas, 1992; Fornasieri Filho & Fornasieri,1993).

No tillage soil management

The conventional soil management has been successfully replaced in many agricultural regions worldwide and particularly in Brazil. In the last decades, the quick degradation of soil under agricultural exploitation worldwide, especially in tropical developing countries has arisen the concern on soil quality and sustainability of the agricultural exploitation. If intensive tillage is responsible for the soil deterioration, its reduction and the accumulation of organic residues at the soil surface could probably change this condition (Silveira Neto et al., 2006). The no-tillage technique has been recommended as alternative to avoid the undesirable effects of inadequate and repetitive soil preparation when intensive tillage practices are used (Chan et al., 1992).

The no-tillage system presents as main characteristic the implementation of culture without drastic soil mobilization, in other words, without its preparation or mobilization before sowing, the mobilization occurs only at the sowing line. This type of system also involves the maintenance of vegetal residues from previous cultures at its surface and the diversification of species through culture rotation. According to Seixas et al. (2005), this culture rotation consists of the alternation of vegetal species at the same area and season, where a minimum period of time is observed without the cultivation of the same species.

Soil compaction

The soil compaction consists of the alteration on its structure, generally caused by the traffic of machines and agricultural accessories or by degradation caused by management and tillage operations. It leads to lower agricultural productivity, once it reduces the soil permeability to air and water and makes root penetration difficult (Lanças et al., 1990; Novak et al., 1992; Freitas, 1994; Pedrotti et al., 1998). In this context, the compacted soil presents lower hydric and nutritional availability, resulting in a thin layer to be explored by the root system. The conventional soil management, which presents intense mechanization, worsens the soil compaction problems, and this effect is more evident in annual cultures due to the intense soil mobilization during management operations (Silva et al., 1986).

In the no-tillage system, the sowing is performed under remainders of the previous culture, and the surface layers of the soil profile, when compared to the conventional soil management, generally present higher structural stability, higher density and microporosity values and lower macroporosity and total porosity values after three to four years (Vieira & Muzilli, 1984; Corrêa, 1985). This is mainly due to the non-revolving of the soil and to the pressure from the traffic of machines and agricultural accessories, above all when performed in clayish soils with high water contents (Vieira & Muzilli, 1984; Stone & Silveira, 1999). The traffic of heavy machines in the no-tillage system has caused superficial soil compaction (Silva et al., 2000) and reduced culture productivity (Beutler & Centurion, 2003).

One of the indicatives of soil compaction levels is its density (Mantovani, 1987; Reichardt, 1990; Diaz-Zorita, 2000; Queiroz-Voltan et al., 2000). When the system is correctly managed, with good dead coverage and adequate culture rotation, its density may decrease along the years due to the increase on the organic matter content at the superficial layer, also improving the soil structure (Reeves, 1995; Stone & Silveira, 2001), which will promote the fixation of canals that allow adequate air flow and higher water infiltration rates (Seixas et al.,2005).

The soil cone index may be used as an adequate parameter for the characterization of the soil physical-mechanical conditions and estimations of the soil-machine (trafficability, compaction and soil management methods) and soil-root (mechanical hindrance, growth restrictions) interactions, according to Machado et al. (1999). This index is defined as the soil resistance to the penetration of a conical tip and is expressed as the power per area unit of the cone base up toa given depth (Cunha et al., 2002).

Tormena et al. (1998) and Silva et al. (2002) agree that a soil resistance to penetration value of 2000kPa has been associated to unfavorable conditions for the growth of roots and aerial parts of cultures in general. Canarache (1990) and Mertto & Mundstock, (1999) report that values of mechanical resistance to penetration values ranging from 1000 to 3500kPa may restrict or even hinder the growth and development of roots.For the bean culture, mechanical resistance to penetration values ranging from 1290 to 2870kPa do not restrict the grain yield, according to (Carvalho et al. 2006).

Water retention in the soil

Although the soil management under no-tillage increases the soil density and the root penetration resistance, it also increases the volume of stored water available to plants (Klein & Libardi, 1998). The higher water availability in the no-tillage system is associated to the non-revolving of the soil, its lower temperature and larger amount of superficial dead coverage (Vieira, 1984), which reduces evaporation, increases transpiration and hence increases the culture productivity. The maintenance of residues at the soil surface in the no-tillage system, besides the increase on the water retention, also provides higher protection against the direct rain impact (Igue,1984). The non-revolving of the soil leads to slower and progressive decomposition of the organic matter, thus contributing for the soil and water conservation, also promoting the improvement of its structure that favors aeration and water infiltration, enabling better penetration of the root system (Igue, 1984; Lal, 1986).

A number of works have demonstrated the occurrence of higher water retention under low tensions for soils under no-tillage or minimum tillage (Igue, 1984; Vieira, 1984; Lal, 1986; Salton & Mielniczuk, 1995; Klein & Libardi, 1998; Stone & Silveira, 1999; Stone & Moreira, 2000; Stone & Moreira, 2001). At lower tensions, the pores size distribution is strongly correlated with the water storage. Thus, management systems that cause higher revolving of the soil and therefore higher volume, also store less water at the revolved layer in relation to other identical not revolved layers (Stone & Moreira, 2000).

Root development

Since the no-tillage system improves the soil structure and water availability, a higher root development and hence a higher productivity are expected for this type of soil management; however, the effects of different soil management on root development and bean plant yield are not yet well determined. In general, root elongation is only possible when the root growth pressure is higher than the soil mechanical resistance to penetration. Mechanical resistance to penetration values ranging from 1000 to 3500kPa may generally restrict or even hinder the root development and growth (Canarache, 1990; Merotto & Mundstock, 1999). According to Arshad et al. (1996), these values may range from 2000 to 4000kPa. More specifically for bean crop, Carvalho et al. (2006) concluded that soil mechanical resistance to penetration values ranging from 1290 to 2870kPa are not restrictive to productivity. Stone & Silveira (1999) studied the effect of different soil managements on productivity, water availability and root development of bean crops and verified that the no-tillage system presented higher productivity with higher water economy; however, the root system depth distribution was more uniform in plow-prepared soils. Stone (2002) worked with bean crop for four consecutive years using three soil preparation systems (no-tillage, plowing with plowing grid and moldboard plow) and observed that from 76 to 90% of roots were found at the first 30 cm deep in the soil.

Bean yield

In relation to bean yield, Siqueira (1989) verified higher productivities in conventional management when compared to no-tillage system. In the study of Stone (2002), the no-tillage system presented lower number of pods per plant and lower mass of 100grains and hence lower productivity in relation to the other soil management systems; however, the author attributed the lower bean yield to the lower N content in plants and concluded that the bean plant yield under no-tillage system increases with the adoption time of this system. Other important aspects are related to reductions on productivity in the no-tillage system. Arf et al. (2004) observed that soils prepared with moldboard plow and with plowing grid produced higher amount of grains in relation to the no-tillage system, once the dead coverage of this system provided higher humidity in the soil surface, thus favoring the attack of the “white mould”. Mullins et al. (1980) and Zaffaroni et al. (1991), however, found no differences in the bean plant yield between no-tillage system and conventional management.

Objective

The objective of this work was to evaluate how two different soil management systems, conventional and no-tillage managements, influence the soil water retention, compaction, root development and bean yield, irrigated by central pivot system.

MATERIAL AND METHODS

The study was conducted at the farm of an irrigating producer in the largest irrigated region of the state of São Paulo, Brazil, during the second semester of 2003. The culture selected was bean cultivar Rubi, which sowing occurred at August 02 and harvest at November 25, summing up 116 days of culture cycle. The experimental design was fully randomized with two treatments and 13 repetitions. The experimental parcels were placed under an 18ha central pivot and divided into two soil management types: conventional management (14.4ha) and no-tillage management (3.6ha). The conventional management was performed by means of the use of plow and grid, while the no-tillage management was characterized by sowing performed under remainders of the previous culture with no soil revolving. The denomination no-tillage management was used because the parcel with no soil revolving does not characterize a continuous no-tillage system, once operations such as soil preparation aimed at eliminating the cotton stump and subsoiling for the elimination of compacted soil layers and redistribution of nutrients along the soil profile are periodically performed (Table 1).

Table 1. Culture rotation according to the management program

2001		2002		2003	
1st semester	2nd semester	1st semester	2nd semester	1st semester	2nd semester
Cotton/ oak	Corn	Bean/ oak	Cotton	Oak	Bean

Before the experiment was installed, soil non-deformed samples were collected with the aid of volumetric rings at layers of 0-5cm, 5-10cm, 10-20cm and 20-40cm in both soil management conditions for the attainment of water retention characteristic curves. In order to adjust the pairs of data in relation to soil water tension and the corresponding volumetric humidity, the non-linear equation proposed by Van Genuchten (1980) was used, which parameters were obtained using the Soil Water Retention Curve – SWRC software (Dourado Neto et al., 1990).

Irrigation was monitored by means of three tensiometer batteries in each soil management treatment: conventional management and no-tillage management. Each battery was composed of two tensiometers installed at 15 and 30cm of depth, where the first one defined the irrigation moment and the second one was used to control the amount of water applied (Saad & Libardi, 1992). The irrigations were performed whenever the average value read in tensiometer placed at 15cm of depth reached 35kPa (Silveira & Stone, 1994; Moreira et al., 1999).

For the determination of the soil cone index (soil mechanical resistance to penetration), a hydraulic-electronic penetrometer according to Lanças and Santos (1998) was used. The hydraulic-electronic penetrometer, assembled on a cart for haulage and application in tractors with hydraulic system, presents a cone with base area of 320 mm^2, solid angle of 30º and soil penetration constant velocity of 30 $mm.s^{-1}$ according to ASAE S313.2 (1991). The electronic system presents a data acquisition system (Microloger 23X, Campbell), power sensor (load cell of 10000 N) and depth sensor (rotational potentiometer). The layers used for the determination of the soil cone index were 0-5; 5-10; 10-20 and 20-40cm in both treatments.

The root development was evaluated when 50% of plants were found at full flowering stage and its sampling was performed using a galvanized steel auger with diameter of 4.5cm. The soil collection for the root analysis occurred at days 3 and 4 of November in four layers (0-5; 5-10; 10-20 and 20-40cm). The samples were removed from the tillage line between one plant and another with four repetitions per parcel, summing up 52 samples from each layer per treatment. Later, the roots were separated from the soil through washing in running water with the aid of a 0.5mm sieve. After separated and washed, the root samples were conditioned in universal collectors with alcohol solution 70% and placed into freezer at 4°C. The variables that characterize the root development were determined in a Scanner coupled to a computer equipped with WinRhizo software, which uses the method proposed by Tennant (1975) as principle. This equipment determined length ($Km.m^{-3}$), surface ($m^2.m^{-3}$) and root diameter (cm). After these evaluations, the samples were dried in stove at 65°C until reaching constant weight for the determination of the root dry matter production ($g.m^{-3}$). On the occasion of the bean culture harvest, 10 sequential plants in pre-determined site in the useful area of each parcel were collected. These plants were led to the laboratory for the determination of the number of pod/plant, number of grains/plant, average number of grains/pod and mass of 100grains, determined through random collection and weighting of two samples of 100 grains per parcel.

RESULTS AND DISCUSSION

Figure 1 presents precipitations and irrigations that occurred during the bean plant cycle, 333.5mm and 188.3mm, respectively.

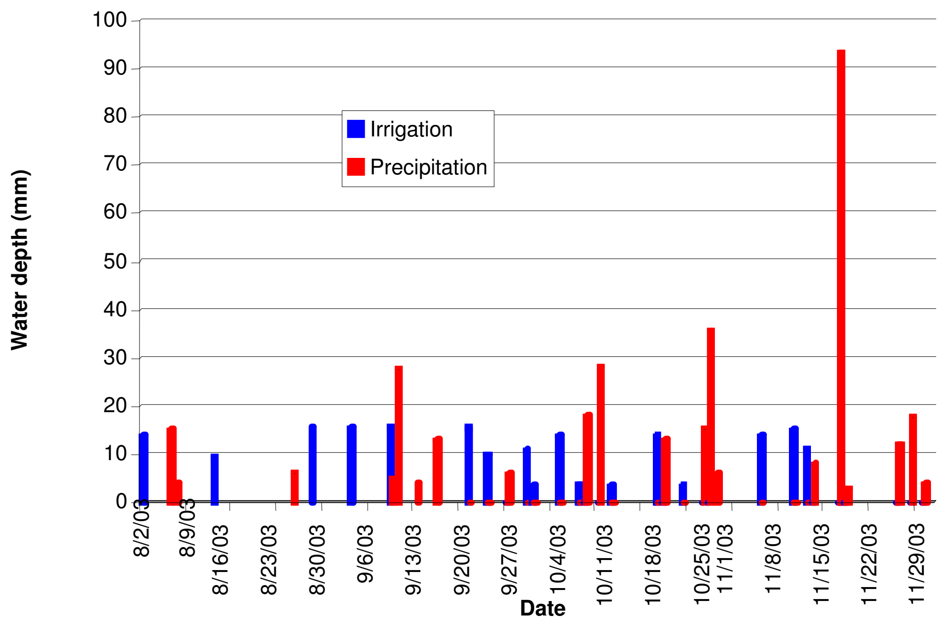

Figure 1. Amount of water x date (irrigation/precipitation). Occurrence of precipitation and irrigation during the bean plant cycle.

According to Doorenbos & Kassam (1979), the hydric demand of the bean culture with cycle from 60 to 120days ranges from 300 to 500mm to reach high productivity.

In at least two days, 09/09 and 10/20/03, rain precipitation with amount of water equal to or above that applied by irrigation was verified. This evidences the importance of climatic monitoring services that provide information on the probability of rain precipitations, once a slight anticipation on the irrigation or even its suspension could represent water and energy economy and avoid favorable conditions for the development of diseases.

For bean culture, irrigation is recommended when the water tension in soil reaches 35kPa (Silveira & Stone, 1994; Moreira et al., 1999). In relation to the monitoring of the water tension, Figures 2 and 3 showed a quite similar trend between conventional and no-tillage management conditions. Since the blue line represents the tension equivalent to soil at the field capacity, in other words, 10kPa and the green line represents the tension of 35kPa, which indicates the irrigation moment, one observes that in some periods, the tension exceeded these two limits. The periods in which tension was close to 0, in other words, close to saturation, are those corresponding to the occurrence of intense rainfalls (09/10 to 09/16/03).

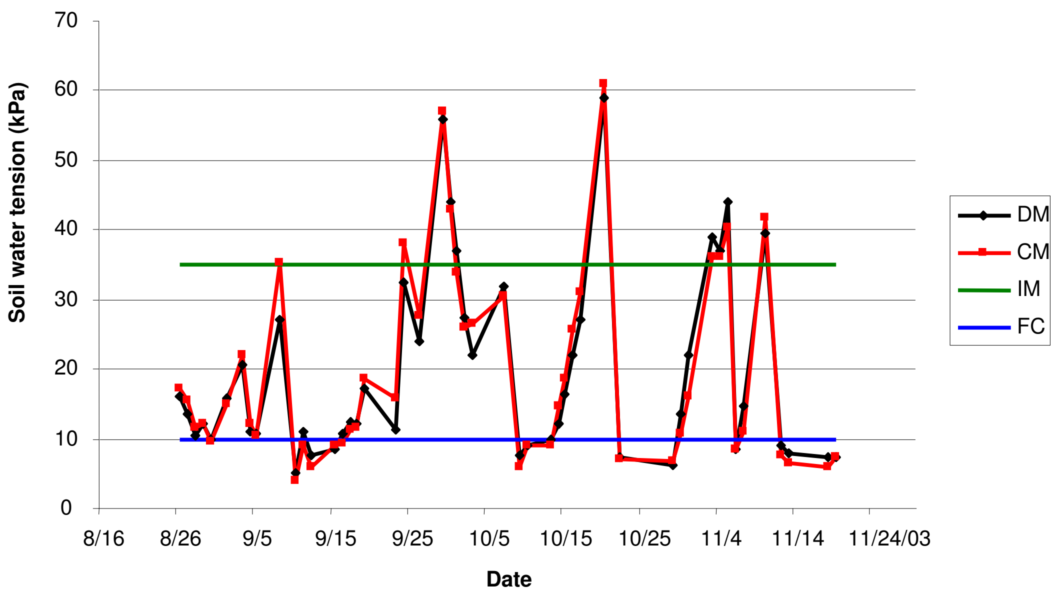

Figure 2. Soil water tension x date. Soil water tension (kPa) at 15cm depth for no-tillage management (DM) and conventional management (CM) conditions, irrigation moment (IM) and field capacity (FC) along the culture cycle.

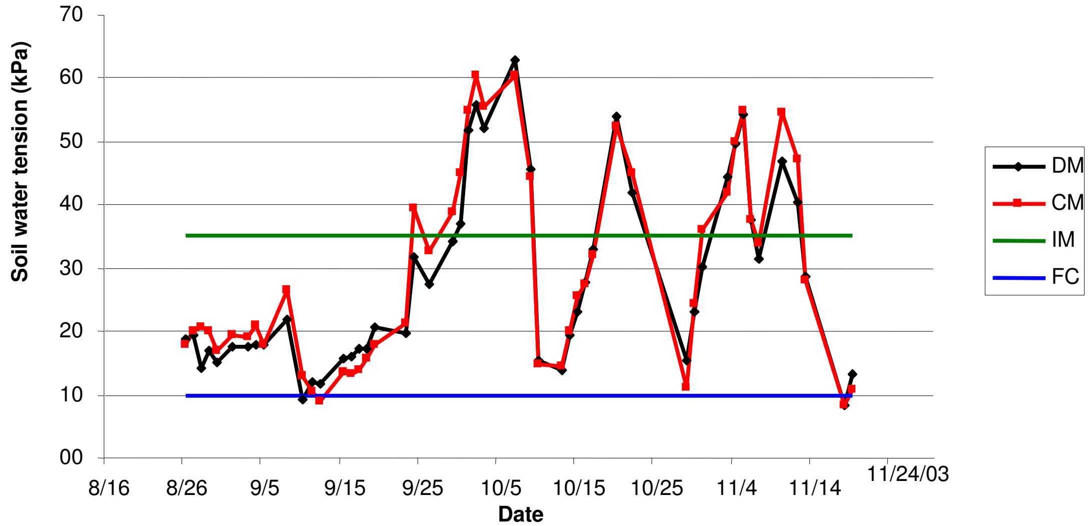

Figure 3. Soil water tension x date. Soil water tension (kPa) at 30cm depth for no-tillage management (DM) and conventional management (CM) conditions, irrigation moment (IM) and field capacity (FC) along the culture cycle.

In some periods, the soil water tension exceeded the limit of 35kPa, leaving the soil drier with the objective of aiding the control of diseases with high damage potential that diffuse in humid environments such as the white mould.

In identical irrigation and precipitation conditions, no-tillage soil management presented higher amount of water available at the most superficial layers (0 to 5cm and 5 to 10cm), identical values at layer from 10 to 20cm and lower amount of water at the deepest layer (20 to 40cm), as shown in Table 2. Higher water availability in no-tillage management at the soil layer from 0 to 10cm was observed by Urchei (1996), who also observed that in soil layers from 10 to 20cm and from 20 to 30cm, both types of soil management conditions presented approximately the same water storage. Considering the effective depth of the bean plant root system ranging from 20 to 30cm (Moreira, 1993; Stone, 2002), the no-tillage management condition seemed to be more effective for water retention up to this depth and hence there may be more water available to plants and lower variation on its content, once the dead coverage in this condition reduces the water losses due to evaporation (Stone & Silveira, 1999; Stone & Moreira (2000, 2001). Other works (Castro et al., 1987; Salton & Mielniczuk, 1995; Klein & Libardi, 1998) have verified that in no-tillage systems or systems with minimum management in which soil is little revolved or not revolved at all, a higher water retention is observed. According to Vieira (1984), the higher water availability in no-tillage system is associated to the soil non-revolving, lower temperature and larger amounts of superficial dead coverage, which increased the surface rugosity and favored higher infiltration rates.

Thus, plants belonging to no-tillage management presented potential conditions of higher root development and hence higher vegetative growth, higher number of flowers and higher grain yield.

Table 2. Field capacity (FC) in cm^3 cm^{-3}, permanent wilting point (PWP) in cm^3 cm^{-3}, available water (AW) in mm cm^{-1}, density (Ds) in $g.cm^{-3}$ and texture at different soil layers for conventional (CM) and no-tillage (DM) management systems.

Soil management	Layer (cm)	FC (cm^3 cm^{-3})	PWP (cm^3 cm^{-3})	AW (mm cm^{-1})	Ds (g cm^{-3})	Texture
CM	0-5	0.3215	0.2764	0.5	1.48	clay
	5-10	0.3172	0.2584	0.6	1.41	clay
	10-20	0.3248	0.2697	0.6	1.41	clay
	20-40	0.3071	0.2418	0.7	1.26	clay
DM	0-5	0.3387	0.2653	0.7	1.23	clay
	5-10	0.3645	0.2934	0.7	1.37	clay
	10-20	0.3885	0.3302	0.6	1.41	clay
	20-40	0.3672	0.3152	0.5	1.36	clay

Since intense mechanization was observed in the conventional management condition, in other words, more traffic of machines, the more superficial soil layers (0 to 5cm and 5 to 10cm) presented higher density values, according to results presented by Silva et al., 1986; Campos et al., 1995. Since the soil density is the most common form to quantify its compaction (Mantovani, 1987; Reichardt, 1990), one may conclude that up to depth of 10cm, the no-tillage management was found less compacted. The soil non-revolving and the lower movement of machines and agricultural accessories, in addition to the effect of the dead coverage that increased the organic matter content, provided an improvement on the soil structure at this depth, thus increasing its aggregates and decreasing its density, what contributes for a higher water storage at this condition, according to results found by Stone & Moreira (2000, 2001). Similarly for the available water, at layer of 10 – 20cm, both soil managements presented the same density, and the deepest layer (20-40cm) was the conventional management condition that presented the lowest soil density.

The soil cone index values showed increase trend up to the layer of 10-20cm for both treatments. In this layer, the highest values for no-tillage and conventional management systems were observed, 3254kPa and 3310kPa, respectively (Table 3). Physically, the root elongation is only possible when the root growth pressure is higher than the soil mechanical resistance to penetration, which may be characterized by the soil cone index. According to Carvalho et al.(2006), the maximum soil cone index value for adequate root development in bean plants is of 2870 kPa, showing that values obtained were restrictive in layer of 10-20cm. According to Canarache (1990) and Merotto & Mundstock (1999), the soil cone index values found in this work can also be restrictive to the root development in most cultures.

Table 3. Soil cone index (kPa) for no-tillage management (DM) and conventional management (CM) conditions at the different soil layers.

Soil management	0-5cm	5-10cm	10-20cm	20-40cm
DM	1104	2736	3254	2335
CM	1095	3161	3310	2702

Thus, the bean plant root system was found at the most superficial soil layers (0-5cm and 5-10cm), presenting total length of 93% at the first 10cm of the soil profile in the conventional management system and 84% in the no-tillage management system (Table 4). The most uniform root distribution in the no-tillage management system may be related to soil cone index values of layer 5-10cm. In this layer, the soil cone index in the no-tillage management system (2736kPa) was lower than that considered restrictive for this culture (2870kPa), what was not observed for the conventional management system (3161kPa). One yet observes that layers of 5-10 and 10-20cm in the conventional management system presented values quite close to each other, 3161kPa and 3310kPa respectively, what might have been caused by adjustment problems of the agricultural accessories work effective depth, thus evidencing alterations at the depth of the compacted subsuperficial layers.

Table 4. Distribution of the bean plant root length along the soil profile at no-tillage (NM) and conventional (CM) management systems for depths evaluated

Soil layer (cm)	NM	CM
0-5	38%	61%
5-10	46%	32%
10-20	11%	6%
20-40	5%	1%

The layer of 5-10cm also presented significant differences in the dry weight of roots (Table 5), of 898.35g.m^{-3} in the no-tillage management system and of 598.59g.m^{-3} in the conventional management system. For the other root development variables, no significant differences between treatments were observed. The most uniform root distribution results in no-tillage management are not in agreement with Stone & Silveira (1999), who obtained better distribution in plow-prepared soil.

Table 5. Length (km.m^{-3}), surface (m^{2}.m^{-3}), dry weight (g.m^{-3}) and root diameter (cm) of the bean plant in no-tillage management system (NM) and conventional management system (CM) at the different layers evaluated.

Soil layer (cm)	Length (km.m^{-3})		Surface (m^{2}.m^{-3})		Dry Weight (g.m^{-3})		Diameter (cm)	
	NM	CM	NM	CM	NM	CM	NM	CM
0-5	9.04a	16.66a	14.37a	22.35a	733.15a	924.55a	0.054a	0.046a
5-10	10.98a	8.67a	19.93a	11.82a	898.35a	598.59a	0.059a	0.048a
10-20	2.68a	1.53a	5.28a	3.26a	339.38a	263.67a	0.056a	0.059a
20-40	1.11a	0.28a	1.72a	0.44a	93.53a	74.70a	0.048a	0.042a

Values followed by same letter in the line are not significantly different at 5% probability through the Tukey test.

However, distribution differences in the root system and dry weight of roots were not sufficient to influence the bean yield of bean plants between treatments (Table 6). These results are similar to those obtained by Mullins et al. (1980) and Zafarroni et al. (1991), who also found differences in bean yield between no-tillage and conventional management systems.

Table 6. Number of grains per plant, number of grains per pod, mass of 100 grains and bean plant productivity for both soil managements.

Soil management	Number of grains per plant	Number of pods per plant	Number of grains per pod	Mass of 100 grains (g)	Bean Yield ($Kg.ha^{-1}$)
No-tillage management	83.48a	15.22a	5.14a	18.02a	3360a
Conventional management	78.41a	16.22a	5.16a	19.47a	3330a

CONCLUSIONS

Up to the depth of 10cm, the no-tillage system presented lower soil density value, lower compaction and higher water storage capacity in relation to the conventional management. The root system distribution in the 0-40cm layer was more uniform in no-tillage management system in relation to the conventional one. The no-tillage management system presented higher root dry weight value than the conventional management system at layer of 5-10 cm. However, these soil management systems presented no significant differences for bean plant yield and for the other production components evaluated.

REFERENCES

Arf, O., Rodrigues, R. A. F., Sá, M. E., Buzetti, S., Nascimento, V. Manejo do solo, água e nitrogênio no cultivo de feijão. **Pesquisa Agropecuária Brasileira**, Brasília, v.39, n.2, p.131-138,2004.

Arshad, M.A.; Lowery, B. & Grossman, B. Physical tests for monitoring soil quality. In: DORAN, J.W. & JONES, A.J., eds. Methods for assessing soil quality. Madison, Soil Science Society of America, 1996. p.123-141 (SSSA Special publication, 49).

Beutler, A.N.; Centurion, J.F. Compactação do solo no desenvolvimento radicular e na produtividade da soja. **Pesquisa Agropecuária Brasileira**, v.39, 2004. p. 581-588.

Canarache, A. Penetr-a generalized semi-empirical model estimating soil resistence to penetration. **Soil & Tillage Research**, Amsterdam, v.16, 1990. p. 51-70.

Carvalho, G. J., Carvalho, M. P., Freddi, O. S., Martins, M. V. Correlação da produtividade do feijão com a resistência à penetração do solo sob plantio direto. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.10, n.3, 2006. p. 765–771.

Chan, K.Y.; Roberts, W.P.; Heeman, O.F. Organic carbon and associated soil properties of a red earth after 10 years of rotation under different stubble and tillage practices. **Australian Journal of Soil Research,** Melbourne, v.30, 1992. p. 71-83.

Corrêa, J.C. Efeito de métodos de cultivo em algumas propriedades físicas em um Latossolo Amarelo muito argiloso do Estado do Amazonas. **Pesquisa Agropecuária Brasileira**, Brasília, v.20, n.11, 1985. p. 1317-1322.

Costa, F.S.; Albuquerque, J.A.; Bayer, C.; Fontoura, S.M.V.; Wobeto, C. Propriedades físicas de um Latossolo Bruno afetadas pelos sistemas plantio direto e preparo convencional. **Revista Brasileira de Ciências do Solo,** v.27, 2003. p. 527-535.

Cunha, J.P.A.R.; Vieira, L.B.; Magalhães, A.C. Resistência Mecânica do Solo à Penetração Sob Diferentes Densidades e Teores de Água. **Engenharia na Agricultura**, v.10, n.1-4, 2002.

Díaz-Zorita, M. Effect of deep-tillage and nitrogen fertization interactions on dryland corn (*Zea mays* L.) productivity. **Soil & Tillage Research**, Amsterdam, v. 54, 2000. p. 11-19.

Folle, S.M.; Seixas, J.M. Mecanização agrícola. In:GOEDERT, W.J. (Ed). **Solos dos cerrados**: tecnologias e estratégias de manejo. São Paulo: NOBEL/EMBRAPA CPAC, 1986, p.385-408.

Fornasieri Filho, D.; Fornasieri, J.L. **Manual da cultura de arroz.** Jaboticabal: Funep, 1993. 221 p.

Freitas, P.L. Manejo físico do solo. In: SIMPÓSIO SOBRE MANEJO E CONSERVAÇÃO DO SOLO NO CERRADO, 1., 1990, Goiânia. **Anais.** Campinas: Fundação Cargill, 1992. p. 117-139.

Freitas, P.L., de. Aspectos físicos e biológicos do solo. In: LANDERS, J.N. (Ed). **Experiências de plantio direto no Cerrado.** Goiânia: APDC, 1994. p.199-213.

Gonçalves, C.N., Ceretta, C.A. Plantas de cobertura de solo antecedendo o milho e seu efeito sobre o carbono orgânico do solo, sob plantio direto. **Revista Brasileira de Ciências do Solo,** Viçosa (MG), v.23, n.2, 1999. p. 307-313.

Igue, K. **Dinâmica da matéria orgânica e seus efeitos nas propriedades do solo**. In: ADUBAÇÃO VERDE NO BRASIL. Campinas: Fundação Cargill, 1984. p.232-267.

Klein, V.A., Libardi, P.L. Armazenagem de água no solo e resistência à penetração. In: REUNIÃO BRASILEIRA DE MANEJO E CONSERVAÇÃO DO SOLO E DA ÁGUA, 12. 1998. Fortaleza/Ceará. **Resumos expandidos.** Sociedade Brasileira Ciências do Solo. Universidade Federal do Ceará. 1998. p.163-164.

Koppi, A.J.; Douglas, J.T. A rapid inexpensive and quantitative procedure for assessing soil structure with respect to cropping. **Soil Use Management**, v.7, 1991. p. 52-56.

Lal, R.; Pirce, F. J. The vanishing resource. *In*: LAL, R.; PIRCE, F. J. (Ed.). **Soil managment for sustainability**. Ankeny: Soil and Water Conservation Society, 1991. p. 1-5.

Lanças, K.P., Benez, S.H., Furlani Jr, J.A., Gamero, C.A., Antuniassi, U.R. Subsolador: desgaste em função da sua dureza superficial. In: Congresso Brasileiro de Engenharia Agrícola, 19., Piracicaba, SP. 1990. **Anais.** Piracicaba, SP. 1990. p. 801-809.

Machado, A.L.T., Trein, C.R., Bica, A.V.D., Boeni, M. Desenvolvimento e aplicação de um penetrógrafo eletrônico. In: CONGRESSO BRASILEIRO DE ENGENHARIA AGRICOLA, 28, A Engenharia Agrícola – TENDÊNCIAS E INOVAÇÕES. 1999, Pelotas, RS, **Anais...** Pelotas/RS, (CD ROM). 1999.

Mantovani, E.C. Compactação do solo. **Informe Agropecuário,** Belo Horizonte, v.13(147), 1987. p. 52-55.

Merotto, A. & Mundstock, C.M. Wheat root growth as affected by soil strength. **Revista Brasileira de Ciência do Solo**, v.23, 1999. p. 197-202.

Mullins, C.A.; Tompkins, F.D.; Parks, W.L. Effects of tillage methods on soil nutrient distribution, plant nutrient absorption, stand, and yield of snap beans and lima beans. **Journal of the American Society of Horticultural Science**, Alexandria, v.105, 1980. p. 591-593.

Novak, L.R., Mantovani, E.C., Martyn, P.J., Fernandes, B. Efeito do tráfego de trator e da pressão contato pneu/solo na compactação de um Latossolo Vermelho-Escuro álico, em dois níveis de umidade. **Pesquisa Agropecuária Brasileira,** Brasília, v.27, 1992. p. 1587-1595.

Pedrotti, A., Vahl, L.C., Pauletto, E.A. Níveis de compactação do planossolo e o desenvolvimento radicular de algumas culturas. In: REUNIÃO BRASILEIRA DE MANEJO E

CONSERVAÇÃO DO SOLO E DA ÁGUA, 12. 1998. Fortaleza/Ceará. **Resumos expandidos.** Sociedade Brasileira Ciências do Solo. Universidade Federal do Ceará. 1998. p. 89-90.

Queiroz-Voltan, R.B.; Nogueira, S.S.S.; Miranda, M.A.C. Aspectos da estrutura da raiz e do desenvolvimento de plantas de soja em solos compactados. **Pesquisa Agropecuária Brasileira**, v.35, 2000. p. 929-938.

Reeves, D.W. Soil management under no-tillage: soil physical aspects. In: SEMINIRIO INTERNACIONAL DO SISTEMA PLANTIO DIRETO, 1., 1995, Passo Fundo. **Resumos**. Passo Fundo: Embrapa-CNPT, 1995. p. 127-130.

Reichardt, K. **A Água em Sistemas Agrícolas.** Barueri, SP: Manole, 1990.

Salton, J.C.; Mielniczuk, J. Relações entre sistemas de preparo, temperatura e umidade de um Podzólico Vermelho Escuro de Eldorado do Sul (RS). **Revista Brasileira de Ciência do Solo**, v.19, 1995. p. 313-319.

Seixas, J.; Roloff, G.; Ralish, R. Tráfego de máquinas e enraizamento do milho em plantio direto. **Ciência Rural**, Santa Maria, v.35, n.4, 2005. p. 794-798.

Silva, A.P., Libardi, P.L., Camargo, O.A. Influência da compactação nas propriedades físicas de dois Latossolos. **Revista Brasileira de Ciência do Solo,** v.10, 1986. p. 91-95.

Silva, V.R.; Reinert, D.J.; Reichert, J.M. Resistência mecânica do solo à penetração influenciada pelo tráfego de uma colhedora em dois sistemas de manejo do solo. **Ciência Rural**, v.30, 2000. p. 795-801.

Silva, A. P.; Tormena, C. A.; Imhoff, S. Intervalo hídrico ótimo. In: MORAES, M. H.; MÜLLER, M. M. L.; FOLONI, J. S. S. **Qualidade física do solo**: métodos de estudo-sistemas de preparo e manejo do solo. Jaboticabal: Funep, 2002. p. 1-18.

Silveira, P.M.; Stone, L. F. **Manejo da irrigação do feijoeiro: uso do tensiômetro e avaliação do desempenho do pivô central.** Goiânia: EMBRAPA, p.46 1994. (Circular Técnico, 27).

Silveira Neto, A. N., Silveira, P. M., Stone, L. F., Oliveira, L. F. C. Efeito de manejo e rotação de culturas em atributos físicos do solo. **Pesquisa Agropecuária Tropical**, v.36, n.1, 2006. p. 29-35.

Stone, L. F. **Efeito de lâminas de irrigação e preparo do solo na resposta do feijoeiro ao nitrogênio em cobertura.** Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2002. 24p.

Stone, L. F.; Moreira, J.A.A. Efeito de sistemas de preparo do solo no uso da água e na produtividade do feijoeiro. **Pesquisa Agropecuária Brasileira,** v.35, n.4, 2000. p. 835-841

Stone, L.F.; Moreira, J.A.A. Resposta do feijoeiro ao nitrogênio em cobertura, sob diferentes lâminas de irrigação e preparos do solo. **Pesquisa Agropecuária Brasileira,** Brasília, v.36, n.3, 2001. p. 473-481.

Stone, L. F.; Silveira, P. M. Efeito do sistema de preparo na compactação do solo, disponibilidade hídrica e comportamento do feijoeiro. **Pesquisa Agropecuária Brasileira,** v.34, 1999. p. 83-91.

Tormena, C.A.; Silva, A.P.; Libardi, P.L. Caracterização do intervalo hídrico ótimo de um Latossolo Roxo sob plantio direto. **Revista Brasileira de Ciência do Solo**, v.22, 1998. p. 573-581.

Vieira, M.J. Propriedades físicas do solo. In: IAPAR (Londrina, PR). **Plantio Direto no Estado do Paraná.** Londrina, 1981. p.19-32. (IAPAR. Circular, 23).

Vieira, M.J. O preparo do solo e o comportamento da planta. **Plantio Direto**, Ponta Grossa, v.1, n.5, 1984. p. 4-5.

Vieira, M.J.; Muzilli, O. Características físicas de um Latossolo Vermelho-Escuro sob diferentes sistemas de manejo. **Pesquisa Agropecuária Brasileira**, Brasília, v.19, n.7, 1984. p. 873-882.

Zaffaroni, E.; Barrod, H.H.A.; Nobrega, J.A.M.; Lacerda, J.T.; Souza Junior, V.E. Efeito de métodos de preparo do solo na produtividade e outras características agronômicas de milho e feijão no Nordeste do Brasil. **Revista Brasileira de Ciência do Solo.** Campinas, v.15, n.1, 1991. p. 99-104.